5 DECISIONS, DECISIONS!!!

TO REGULATE OR NOT TO REGULATE

It is not easy for a community to evaluate the probable effects of introducing into its building regulatory process new or more stringent seismic design and construction requirements.

- Communities like some in California that are used to experiencing small to moderate seismic events are continually aware of the threat and already have taken some protective measures. To those communities, any changes in their current regulations likely would have to be justified by a soundly based cost-benefit analysis.

- Communities in seismic risk areas with no memorable seismic experience often have little, if any, concern for regulating the seismic resistance of their buildings. Some probably could never be convinced, short of an actual damaging earthquake, that any change in the *status quo*, regardless of its potential advantages, would be worth the effort.

- The conscientious community that falls somewhere between these two types will have to keep in mind that bringing about change in local practices undoubtedly will have differing effects on various segments of the community, some of which will generate interest, and others, concern.

As noted in Chapter 4, a building code is intended to ensure that a building or facility is so located, designed, and constructed that, if it is subjected to natural or man-made destructive forces, it will present no particular threat to the life, health, and welfare of its occupants or the general public. In addition, a building code is intended to ensure uniform minimum standards of health and safety with reasonable economy and to obviate the need for expensive and difficult studies based on first principles for every building project, large or small.

The concerns about seismic code provisions most often voiced are described below.

DO SEISMIC DESIGN REQUIREMENTS REALLY WORK?

Although no specific quantitative information is available to determine the effectiveness of seismic codes (for example, the number of lives actually saved and injuries prevented), experience in recent earthquakes gives convincing proof that properly designing buildings to meet a modern seismic code will dramatically reduce the impact of an earthquake. Although the magnitude of the earthquake that occurred in 1933 in Long Beach, California, was moderate (Richter magnitude 6.3), the damage to buildings was widespread. One of the occupancies to suffer the worst were the public schools (see the photos on the following page). Within seconds, an estimated 75 percent of the public school buildings were heavily damaged and many collapsed. It was readily apparent to responsible public officials that a horrifying number of students and teachers would have been killed and injured if the earthquake had occurred during regular school hours.

This experience resulted in a prompt legislative response to ensure that future public school buildings would be designed and constructed with sufficient earthquake resistance to protect occupants from death or injury. The history of this legislation, and its effect on building performance in subsequent earthquakes, provides some useful lessons for other areas that now find themselves confronted by the realization of an earthquake threat.

The California legislation stimulated by the Long Beach earthquake, the *Field Act*, became effective as an emergency measure one month after the earthquake. It applied only to the design and construction of public school buildings used for elementary, secondary, or community college purposes; private schools, the state college system, and the University of California campuses were not involved. Thus, the act related to facilities at which attendance was compulsory (with the exception of community colleges). The act's principal provisions require that all construction plans be prepared by qualified persons (architects or structural engineers) and that the designs be checked by an independent state agency, which was identified as the Structural Safety Section of the Office of the State Architect. The plan checking is financed by fees, based on the cost of construction, charged against school districts submitting plans for approval.

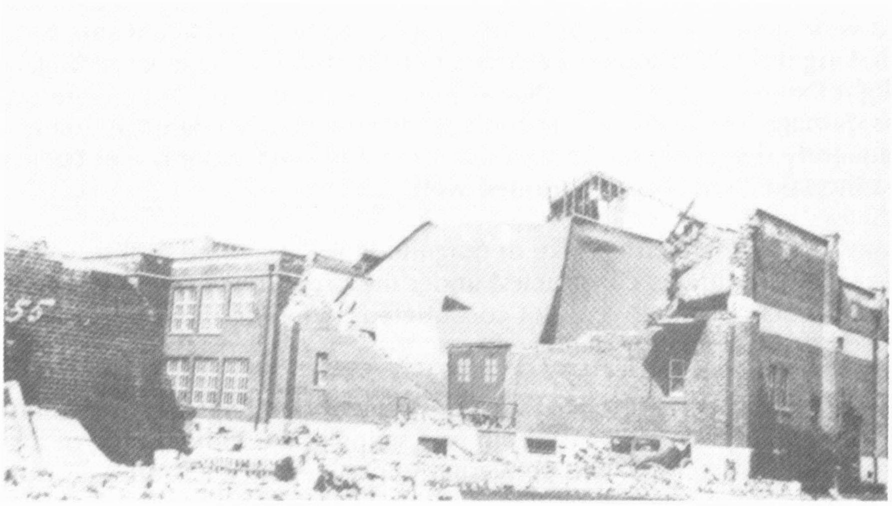
The independent review generally is considered to be one of the most important parts of the *Field Act*. The review has always been rigorously administered by experienced designers. It is aimed at enforcing the state building code and identifying design errors and omissions and conceptual errors of judgment that might result in inadequate earthquake resistance.

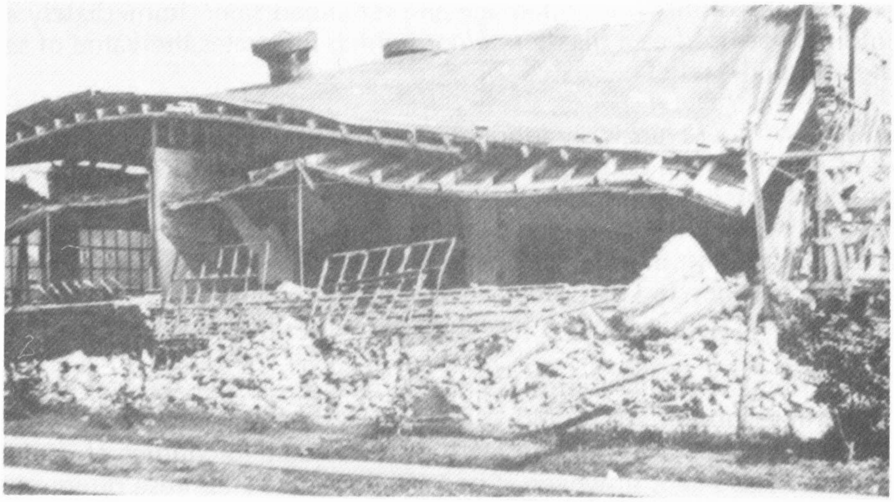
Another very important part of the *Field Act* requires construction to be continually inspected by a qualified person approved by the designers and retained by the school board to see that all of the design requirements are carried out. This inspector is independent of the contractor or architect. All parties with assigned responsibilities, including the architect, consulting engineer, inspector and contractor, must submit verified reports stating that the construction complies with all requirements of the approved plans and specifications. The state also is authorized and required to make any inspections of the buildings and construction judged necessary to enforce the law.

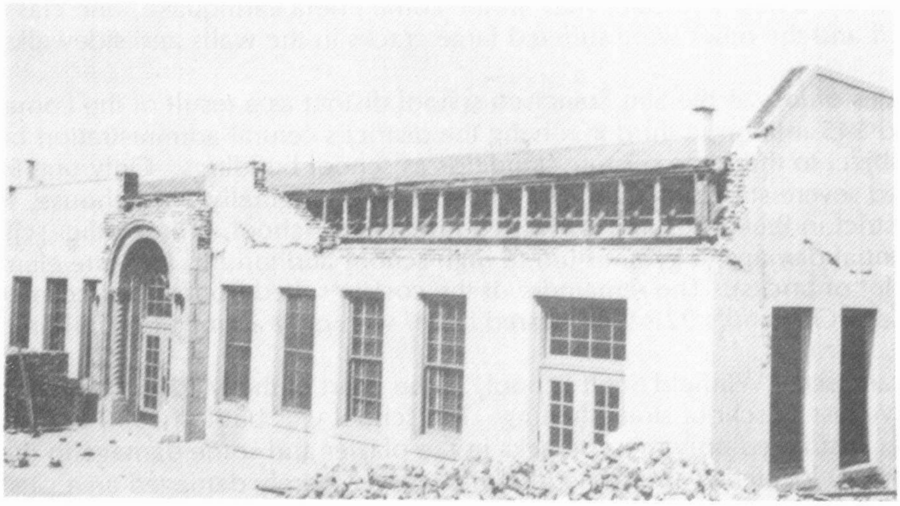
The *Field Act* generally is regarded in California as having been immensely successful in assuring reasonable compliance with acceptable levels of earthquake resistance. It should be noted that the act was in effect during the enormous post-war expansion of population in California and correspondingly massive public school building programs. Although the seismic design review process resulted in an increase of some 2 to 3 months in plan processing and undoubtedly increased the costs of both design and construction, no substantive criticism or limitation has ever been directed at the program.

Since the *Field Act* was implemented, school buildings in California have been tested in a number of earthquakes, and, to date, no students or teachers have been killed or injured in a post-*Field Act* school building during an earthquake. The damaging Kern County earthquakes of 1952 involved one earthquake of Richter magnitude 7.6 followed a month later by one of magnitude 5.8. Of 40 schools constructed prior to the *Field Act*, 40 percent suffered severe damage, 33 percent suffered moderate damage, 25 percent suffered slight damage, and 2 percent had no damage. Of the 18 schools constructed in accord with the *Field Act*, 61 percent had no damage, 33 percent suffered slight damage, and only 6 percent had moderate damage. The fact that some non-life-threatening damage was suffered by *Field Act* schools is an indication that the requirements are not too restrictive.

School damage after the 1933 earthquake in Long Beach.







In December 1954, an earthquake of magnitude 6.6 occurred in the Eureka area north of San Francisco. It caused considerable minor damage to non-*Field Act* schools and no damage to post-*Field Act* schools. The San Fernando earthquake of 1971 (magnitude 6.6) caused shaking over a wide area. No *Field Act* schools received any significant structural damage although the shaking did cause some hazardous nonstructural damage to ceilings, ventilation diffusers, and light fixtures; since the earthquake occurred at 6 a.m., there were no casualties as a result of this damage. Pre-*Field Act* schools received extensive damage; many were closed and subsequently demolished. Several other pre-*Field Act* schools had been strengthened prior to the earthquake, and these performed well.

On May 2, 1983, an earthquake of magnitude 6.7 occurred in the area of Coalinga, California. Public school buildings constructed under the provisions of the *Field Act* performed quite well while some schools that were not constructed under the provisions of the act partially collapsed or were heavily damaged.

The Coalinga junior high school includes several buildings that had been constructed prior to the enactment of the *Field Act*. Both end spans of the roof framing of a gymnasium, which had been constructed in 1928 and converted to maintenance use after an examination declared it to be unsafe, collapsed to the floor. The building subsequently was demolished. In contrast, at West Hills College in Coalinga, the gymnasium with a 96 feet span designed under *Field Act* provisions suffered only minor damage and remained safe. Immediately after the earthquake, the building was used as a disaster center, which illustrates the value of safe school buildings to post-earthquake relief efforts.

In the 1987 Whittier Narrows earthquake, damage to schools in Los Angeles was minimal and limited to nonstructural components and contents. A recent serious test of school buildings was the 1989 Loma Prieta earthquake, a magnitude 7.1 event that affected the entire San Francisco Bay area. A survey of 1,544 public schools in the impacted area showed an estimated $81 million in damage. Only three schools--one in San Francisco, one in Watsonville, and one in Los Gatos--sustained severe damage. Many public school buildings were used as evacuation shelters for the earthquake victims.

The Loma Prieta school buildings in Los Gatos, close to the epicenter of the 1989 earthquake, were constructed in the 1950s and 1960s over hidden branches of the San Andreas fault system. At that time, there was no legislative mandate for studies of geologic hazards at school sites. Several years ago, however, it became apparent that these buildings were sited over potentially active fault traces and, since then, the school system and the state have attempted to purchase a new and safer site. In the Loma Prieta earthquake, one classroom wing heaved upward and the other wing suffered large cracks in the walls and sidewalks.

Estimates of loss to the San Francisco school district as a result of the Loma Prieta earthquake exceed $45 million, a third involving the district's central administration buildings, which are not subject to the same seismic standards as school buildings. Only one San Francisco school suffered severe structural damage. This building, originally a warehouse, was purchased by the district in the 1950s and converted into a high school. Three other schools reported substantial damage (a gymnasium, a high school auditorium, and one elementary school that lost a lot of bricks). The remainder of the costs resulted from minor cosmetic damage at many facilities. Oakland's 92 schools fared better with only about $1.5 million in damage.

San Francisco's Winfield Scott School, in the heart of the Marina area, showed the effectiveness of school strengthening. The school was built in 1930 and strengthened in the 1970s. It suffered only minor cracks in the plaster and some damage to the playground even though it is located in the center of what was a severely damaged area. Its losses were estimated at less than $100,000 and it played an important role in sheltering Marina residents displaced from their dwellings.

In the 1994 earthquake in Northridge, California, no public school building suffered even partial collapse. Further, no structural elements such as beams or columns failed and fell to the floor. Spalling and cracking of concrete occurred in a number of places in several structures; however, all structural damage of this sort could be repaired and the buildings restored to their previous earthquake-resistant capacity. The Superintendent of Schools for the Los Angeles School District stated in testimony to the state Seismic Safety Commission: "I believe in the *Field Act*. I think that if we had not had the *Field Act*, it would have been a complete catastrophe."

Thus, the structural performance of schools in the Northridge earthquake was good; however, considerable nonstructural damage resulted and, had the earthquake not occurred in the early morning hours when school was not in session, many casualties could have resulted. The extent to which students followed their "duck, cover, and hold" training would have had a great bearing on the incidence of injuries. Because the area affected by the Northridge earthquake contains only a few schools constructed since the mid-1970s when nonstructural components began to be increasingly covered by the state's regulations, this earthquake did not provide a comprehensive test of the adequacy of current procedures.

To date, the intention of the *Field Act* appears to have been met. However, the ultimate test – a great earthquake comparable to the 1906 San Francisco earthquake of magnitude 8.3 occurring while schools are in session – has not yet been encountered. Officials in California are confident that decades of application of the *Field Act* should greatly reduce the damage and casualties resulting from such an event.

DOES SEISMIC DESIGN AND CONSTRUCTION COST A LOT?

Although the main purpose of seismic design is to save lives and prevent injuries, the decision to design against earthquakes and to establish seismic design standards often is based on economic considerations: By how much can we afford to reduce the risk of damage to our building? Because modern facilities are very expensive to build and operate, the economics of seismic design are particularly critical.

It is widely believed that seismic resistant design and construction are extremely costly. Although it is generally true that some increase in design and construction costs is involved, available data indicate that it is not nearly so great as is sometimes argued. In fact, earthquake resistance need not be expensive, and seismic safety provisions, when incorporated in a sound design from the very beginning of the planning effort by a competent team, actually usually amount to only about 1.5 percent of the cost of construction.

An analysis of the information supplied by those conducting trial designs as a part of the BSSC program resulting in the first edition (1985) *NEHRP Recommended Provisions* indicates that the design and construction costs associated with the seismic upgrade of the structural components of a building will increase the total cost of a building an average of less than 2 percent. Although the data used in this analysis were somewhat limited because only some of the trial designers were required to include the costs associated with nonstructural building components, which in many cases could add considerably to the total cost of a building when designed and constructed in accordance with the *NEHRP Recommended Provisions*, the analysis itself is one of a kind and, hence, tentative though conclusions based on it may be, they are at least based on real data and statistical analysis rather than on "intuition."

In general, the added cost of seismic design will be in increased design and analysis fees, additional materials (steel reinforcement, anchorages, seismic joints, etc.), and additional elements (bracing, columns, beams, etc.). The major factors influencing the increased costs of seismic design to comply with a code reflecting the *NEHRP Recommended Provisions* are:

- The complexity of the building form and structural framing system – It is much more economical to provide seismic resistance in a building with a simple form and framing.

- The overall cost of the structural system in relation to the total cost of the building – For a typical building, the structural system usually represents between 10 and 15 percent of the building cost.

- The stage of design at which increased seismic resistance is considered – The cost of seismic design can be greatly inflated if no attention is given to it until after the configuration of the building, the structural framing plan, and the materials of construction have been selected.

In the best case (a simple building with short spans where earthquake requirements are introduced at a very early stage of project planning), the increased cost for seismic design should be in the range of 1 to 4 percent of the structural system or between 1.5 and considerably less than 1 percent of the building cost. In the worst case (a complex, irregular building with long spans where earthquake requirements are considered only after the major design features are frozen), the increase can be considerably more – perhaps as large as 25 percent of the structural cost or up to almost 5 percent of the building cost. In addition, because of the importance of utilities and other nonstructural elements, an additional cost must be estimated for ensuring their protection, but this should not exceed 0.5 percent of construction cost.

Thus, the average increase in cost of buildings conforming to a code reflecting the *NEHRP Recommended Provisions* should be less than l.5 percent of the construction cost of the building, which, of course, is only a part of the total project costs. The actual construction cost of an elementary school, for example, is only about 50 percent of the total project cost, which also includes technical expenses, administrative expenses, land cost, and site development. The cost of equipping a modern building further reduces the impact of a small increase in construction cost. And, because of the high level of wages and salaries, the capital cost of construction represents only a small percentage of yearly operating costs.

These costs also can be considered to be a kind of insurance against the failure of individual elements and pieces of equipment in the building. When looked at in this way, such expenditures take on a new perspective. For instance, the difference between disruption of electricity in a building and severe damage to or destruction of a $50,000 emergency power generator or electrical transformer may lie in an additional $250 for seismic snubbers or restraints. The cost implications of damage to expensive equipment are great in terms of both direct repair or replacement costs and indirect costs resulting from the effect of unusable equipment on building operations.

It is illustrative to examine the increased costs and benefits of seismic design in terms of the rate of return to the building owner (whether an individual or a community) and the public on the increased investment in the building over a 25-year period. This assumes that a damaging earthquake will occur before the end of the 25 years, which is a reasonable probability in many areas.

Consider an elementary school for example. If two alternatives – with and without seismic design – are compared, the rate of return on the extra investment can be determined. This rate of return is the initial rate that the investment would have to be earning if, after 25 years, the community wanted to use the investment to pay for earthquake damage to the school, repairs that would need to be paid for in future inflated dollars.

For the purposes of this example, consider a 50,000 square foot elementary school building with a construction cost of $60.00 per square foot with 25 percent of the cost attributable to the structural and foundation systems, 21 percent to the mechanical and plumbing systems, 13 percent to the electrical system, 33 percent to the architectural systems, and 8 percent to fixed equipment. The cost of seismic design is estimated to be 5 percent of the cost of the structural system or 1 percent of total building construction. (Remember that construction cost represents only a portion of total project cost which also includes design, land acquisition, and site development costs.)

The assumptions for this example are as follows:

- The school costs $3,000,000 to construct without seismic design and $3,037,500 to construct with seismic design.
- At the end of 25 years (with a 4 percent inflation rate), the school without seismic design will be worth $7,998,000 and the school with seismic design will be worth $8,097,975.
- In future dollars, the earthquake damage to the school without seismic design will be $1,199,700 (damage to 15 percent of the structure, 15 percent of mechanical/electrical systems, and 15 percent to the architectural components) and to the school with seismic design will be $267,933 (damage to 5 percent of the mechanical/electrical systems and architectural components).
- The extra finance charges for the $37,500 investment for seismic design will be $125,344 in future dollars (25 year loan at 8 percent).

Thus, the total future extra costs of the school without seismic design would be $906,398 (a negative $99,975 difference in building worth, a negative $931,767 difference in damage repairs, and a positive $125,344 for the principal and finance charges for the seismic investment) and a 13 percent investment would be needed to receive a similar return on the original seismic design investment. In another words, the school board would have had to invest $37,500 (the original cost of seismic design) at 13 percent per year for 25 years to be able to pay for school repairs. In essence, then, seismic design for the school represents both increased life safety of the community's children and a sound investment economically.

If the earthquake damage was severe, the financial loss would affect not only the educational facility and the community as a whole but also the staff and other businesses and professionals who provide goods and services to the school. Earthquake damage therefore will have a very broad effect on community business activities.

Although economic analyses of new construction requirements can be useful in decision-making, their results do not, and should not, necessarily control the decision-making in this area since what is at risk are the people who live, work, and play in a community's buildings. Indeed, the goal of building code requirements is life safety; consequently, trade-offs between construction costs and protection of life must be made concerning seismic resistance just as they are concerning other aspects of design that affect life safety.

WHAT ABOUT RESPONSIBILITY AND LIABILITY?

Questions of responsibility and liability are very real ones even if there are no clear cut answers.

Structural engineers participating in the BSSC program have expressed considerable concern about professional responsibility. Several have voiced strong opinions about their professional responsibility to advise a client about the need for seismic-resistant design even though the local building code does not require it.

Use of the *NEHRP Recommended Provisions* in upgrading a code that includes no seismic considerations will require many design practice changes. During the early phases of the BSSC trial design effort, concern was expressed about the lack of seismic design knowledge and experience of some of the engineers employed by contractors selected to design the hypothetical buildings. This proved to be something of a "red herring," however, in that knowledge and familiarity obviously increase with each design performed. Further, both the BSSC and other technical groups (including the national model code groups whose seismic requirements are based on the *Provisions*) have been and continue to offer courses on application of the *Provisions* requirements.

In addition, although they cannot yet be quantified, liability risks should be considered by all those responsible for buildings. Few data are available that reflect the magnitude of the risks that building decision-makers face in terms of liability for casualties incurred in their buildings during an earthquake, but this will almost certainly be decided by the courts eventually. As soon as the earthquake threat is identified and means of reducing its effect are documented, it can no longer be considered an "act of God" and the owner who makes no reasonable provision for seismic design will be in a very tenuous legal situation when an earthquake occurs. In fact, it was suggested by one municipal code administrator participating in the BSSC program that the best instructional manual regarding responsibility for building safety would be the proceedings from a local court case.

Further, it has been determined in California, for example, that school board members are individually liable for the occupants of a school building if the building has been found to be unsafe and proper steps have not been taken to correct the deficiencies or close the building. Needless to say, when the school boards in California became aware of this liability, they pursued every means necessary to correct unsafe buildings. Many school boards in the West also are exploring more stringent seismic regulations based on the expected liability that they will incur as a result of the earthquake performance of their school buildings.

Liability for earthquake losses also may have a considerable impact on designers. After the 1985 earthquake in Mexico City, for example, a Mexico resident sought justice in the case of the loss of his family in an apartment building that collapsed as a result of the earthquake. His claims were based on an investigation of the design, materials, and construction of the building, and, as a result, the Mexican federal courts issued arrest warrants for the designers of the building. This case is reported to be the first to be brought against individuals as being responsible for deaths and injuries during an earthquake, but it is unrealistic to expect it to be the last.

POTENTIAL JURISDICTIONAL PROBLEMS

An increase in the costs of a new building caused by requiring improved earthquake protection could result in:

- Less new construction and, as a consequence, a reduced supply of housing (especially for the low-income housing market) and commercial and industrial facilities.
- Fewer amenities in what is being built.
- Businesses deciding to locate in adjacent or nearby jurisdictions where they can build or rent more cheaply.

In the last instance, missing out on potential new businesses and the relocation of existing businesses would affect the job market and revenue situation. Questions concerning these matters can be expected to arise in any community surrounded by jurisdictions with less stringent building regulations, and they will be especially troublesome in those communities located in a large seismic zone that includes many other communities and perhaps two or more states. Concern about being the "first" and, for a while, the only community in an area to require seismic-resistant construction is very real and responding to it is not easy.

One way to reduce potential jurisdictional competition and a community's initial isolation as it initiates seismic safety efforts is to attempt to gain intergovernmental cooperation on a regional basis. A number of organizations have been formed to pursue such an approach (see the listing in Appendix E).

The importance of life safety must be emphasized, but in areas where earthquakes have not occurred for a long time and general awareness of the earthquake threat is low, jobs and taxes may well be viewed by many citizens to be of much more "immediate" concern. Nevertheless, when an earthquake occurs, the impacts on all community systems (especially the adverse social and economic impacts) and the duration of response and recovery can be reduced considerably because of seismic-resistant structures. Communities that have not experienced a natural disaster may be unaware of the traumas caused by such an event and of the long-term hardships usually endured afterwards; dissemination of such information may be quite persuasive.

Even though it is difficult to estimate the economic and social impacts of seismic safety, each community must do so for itself as objectively as possible. Decision-makers must make sure they understand the possible consequences of any increase in costs of new construction, especially the impacts that could be felt by those members of the community who fall in the lower income ranges. At the same time, they must bear in mind such things as a loss expectancy study of the Memphis area that indicated that approximately 3,900 lives could be lost if the area today experienced a seismic event similar to that of 1811-12 centered nearby at New Madrid, Missouri.

The liability issue also should stimulate the building community to do what it can to protect itself from litigation. One key way involves the adoption and enforcement of appropriate seismic building codes. It is also apparent that many members of the building community have a strong enough sense of professional responsibility to recognize the need for seismic design and these individuals should be encouraged to communicate their knowledge and views to their peers.

A number of other forces can affect the seismic safety decision-making process. For example, in known seismic-risk areas, lenders are beginning to require seismic design and earthquake insurance as a condition for their financial support. Furthermore, many industrial and service organizations (e.g., Monsanto in the St. Louis area, Federal Express in the Memphis area, and Boeing in the Seattle area) are beginning to require seismic protection in their facilities. It is becoming increasingly important to those businesses and organizations that rely on sophisticated electronic and computer equipment to avoid operational interruptions and shut-downs. To them, ensuring seismic resistance in their structures is a very small price to pay given what they would lose from a major disruption of their operations. Also, some buildings house priceless art or historic treasures that could never be replaced if the building collapsed; indeed, protecting such treasures might stimulate a community to adopt even more stringent seismic safety requirements that cover nonstructural as well as structural components.

Two recent Presidential executive orders imposing new directives on the federal government may also have an effect on communities. With respect to new construction, Executive Order 12699 requires that new federally owned or assisted buildings be designed and constructed to meet the requirements of either the latest edition of the *NEHRP Recommended Provisions* or the immediately preceding edition. Executive Order 12941 directs federal agencies to evaluate existing federally owned and leased buildings to identify buildings that are potentially hazardous and to plan for the seismic rehabilitation of those so identified.

In short, there are many reasons for safeguarding a building, and these reasons continue to be acted on whether or not a community has seismic-resistant construction standards and whether or not those standards are enforced.

With respect to other potential effects, all of the possible outcomes are not yet known. Seismic resistant design and construction are obviously already occurring with few, if any, adverse impacts in California where they are mandated by a statewide code as well as in areas without seismic code requirements. Therefore, it is fair to assume that many of the changes resulting from seismic resistant design and construction will be absorbed in time just as are other changes resulting from new technology.

INFORMATION SOURCES

The regional earthquake consortia and national information centers identified in Appendix E are valuable resources. Much can be learned from them concerning what is being done in various areas. The building community professional societies and the various materials organizations also listed in Appendix E can be sources of specific information useful to community decision-makers.